PriMera Scientific Engineering
Volume 5 Issue 5 November 2024
DOI: 10.56831/PSEN-05-163
ISSN: 2834-2550

Advances in Experimentation And Numerical Modelling of Bendable Concrete

Type: Editorial Note
Received: October 26, 2024
Published: October 30, 2024

Citation:
RDSG Campilho., et al. "Advances in Experimentation And Numerical Modelling of Bendable Concrete". PriMera Scientific Engineering 5.5 (2024): 34-35.

RDSG Campilho[1,2]*, K Madani[3] and A Houari[4]

[1]*CIDEM, ISEP - School of Engineering, Polytechnic of Porto, Porto, Portugal*

[2]*INEGI, Pólo FEUP, Porto, Portugal*

[3]*Mechanical Engineering Department, LMSS Laboratory, Djillali Liabes University, Algeria*

[4]*Laboratory of Dynamic Motors and Vibroacoustic, University of Boumerdes, Algeria*

***Corresponding Author:** RDSG Campilho, CIDEM, ISEP - School of Engineering, Polytechnic of Porto, Porto, Portugal; INEGI, Pólo FEUP, Porto, Portugal.

Bendable concrete, also known as Engineered Cementitious Composites (ECC), represents a significant advancement in the construction industry due to its enhanced ductility and flexibility compared to traditional concrete. Unlike conventional concrete, which is brittle and prone to cracking under tension, bendable concrete can withstand significant deformation before failure. This is largely due to the inclusion of micro-scale fibers, typically polymer, steel, or other materials, which help control crack propagation and improve tensile strength [1]. One of the primary innovations of ECC is its ability to form tight, distributed micro-cracks rather than large, localized fractures. These micro-cracks allow the material to bend without losing structural integrity, making it ideal for applications that demand high resilience, such as buildings in earthquake-prone areas, infrastructure exposed to heavy traffic, or structures that need to absorb the energy from explosions or impacts [2]. Researchers have conducted extensive studies to assess ECC's performance, especially in environments that experience dynamic loading, such as bridges and high-rise buildings [3]. Experimental studies showed that the fiber-matrix interface is critical in ensuring bendability. Research has focused on optimizing fiber volume fraction and matrix composition for different environmental conditions, including hot and dry climate [4]. Experimental investigations have tested ECC under dynamic loading conditions like shocks and earthquakes. The key advantage is its ability to strain harden under tension, which helps to resist crack formation and maintain structural integrity during seismic events or explosions. This is particularly important for improving the safety of infrastructure in earthquake-prone or high-risk areas [5]. Experimental tests have also been conducted to evaluate ECC's energy absorption and fracture toughness, making it more effective than traditional concrete in withstanding sudden impacts or explosive forces [6]. Studies have examined ECC's performance in extreme climates, including high temperatures and dry conditions, to ensure long-term durability. Experiments have shown that adjusting the composition (e.g., using supplementary cementitious materials like fly ash) can help mitigate issues like shrinkage or reduced workability [7]. Furthermore, durability testing under freeze-thaw cycles and high-temperature exposure reveals that ECC has superior long-term performance, making it an ideal candidate for infrastructures in extreme environments [8].

Numerical modeling of ECC, specifically using the finite element method (FEM), is critical to predict the material's behavior under various loading conditions such as tension, compression, and shear. The FEM is widely used to simulate these behaviors, allowing researchers to model the material's microstructural properties and failure criteria under different environmental conditions and loading scenarios [9]. In FEM models, constitutive laws for materials are critical, and for bendable concrete, the use of damage plasticity models is common [10]. These models simulate how the material transitions from elastic to plastic behavior and eventually reaches failure due to crack initiation and propagation. Studies have shown that by adjusting material parameters like fiber content, researchers can simulate how ECC manages crack width and spacing, providing a more resilient structure compared to conventional concrete [11]. In this context, FEM models have been used successfully to match experimental data, verifying the effectiveness of the material's ductility and energy absorption capabilities [12]. Furthermore, various failure criteria, including maximum principal stress and strain-based models, are implemented to predict when and where the material will fail [13], and damage mechanics procedures as well [14]. Numerical models also include cohesive zone models (CZM) to simulate the bond behavior between the fibers and the cementitious matrix, which is crucial for understanding the interface's strength and durability in reinforced ECC [15]. These numerical methods provide engineers with reliable tools to design and optimize the use of bendable concrete in practical applications.

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